SCHOOL OF CIVIL ENGINEERING

JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-80/9

USE OF SYNTHETIC DEMAND MODELLING TECHNIQUES IN TRANSPORTATION PLANNING FOR SMALL URBAN AREAS IN INDIANA

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Final Report

USE OF SYNTHETIC DEMAND MODELLING TECHNIQUES IN TRANSPORTATION PLANNING FOR SMALL URBAN AREAS IN INDIANA

TO: Harold L. Michael, Director
Joint Highway Research Project

August 26, 1980

File: 3-7-12

FROM: Kumares C. Sinha, Research Engineer
Joint Highway Research Project

Project: C-36-69L

Attached is the Final Report on the HPR Part I Study titled "Use of Synthetic Demand Modelling Techniques in Transportation Planning for Small Urban Areas in Indiana". The research has been conducted by Messrs. Hani S. Mahmassani, James R. Mekemson and Edward W. Hanscom, Graduate Instructors in Research of our staff under the direction of Professor K. C. Sinha, Research Engineer.

The Report here is a summary of the findings of the project. It includes suggested guidelines and procedures for the use of the synthetic approach in travel demand forecasting in small urban areas in Indiana.

This Report is forwarded for review, comment and acceptance by the ISHC and FHWA as fulfillment of the objectives of the research.

Respectfully submitted,

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Final Report

USE OF SYNTHETIC DEMAND MODELLING TECHNIQUES IN TRANSPORTATION PLANNING FOR SMALL URBAN AREAS IN INDIANA: EXECUTIVE SUMMARY

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Project No.: C-36-69L

File No.: 3-7-12

Prepared as Part of an Investigation

Conducted by

Joint Highway Research Project
Engineering Experiment Station
Purdue University

in cooperation with the

Indiana State Highway Commission

and the

U.S. Department of Transportation
Federal Highway Administration

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Purdue University
West Lafayette, Indiana 47907
August 26, 1980

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/IN/JHRP-80/9		

4. Title and Subtitle	5. Report Date
USE OF SYNTHETIC DEMAND MODELLING TECHNIQUES IN TRANSPORTATION PLANNING FOR SMALL URBAN AREAS IN INDIANA	August 26, 1980
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Kumares C. Sinha, Hani S. Mahmassani, James R. Mekemson and Edward W. Hanscom	JHRP-80-9

9. Performing Organization Name and Address	10. Work Unit No.
Joint Highway Research Project Civil Engineering Building Purdue University West Lafayette, Indiana 47907	11. Contract or Grant No. HPR-1(17) Part I
	13. Type of Report and Period Covered Final Report
12. Sponsoring Agency Name and Address Indiana State Highway Commission State Office Building 100 North Senate Avenue Indianapolis, Indiana 46204	14. Sponsoring Agency Code

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration. From Planning Study titled "Use of Synthetic Demand Modelling Techniques in Transportation Planning for Small Urban Areas in Indiana".

16. Abstract

This report presents an executive summary of the research documented in three earlier interim reports covering trip generation, trip distribution and traffic assignment phases. The research developed a procedure for the use of synthetic generation of travel demand information that can be used in small urban areas in Indiana. The results indicated satisfactory performance of the procedure. A set of guidelines was developed for application of the research results in new transportation studies or in updating of existing transportation studies.

17. Key Words	18. Distribution Statement
Urban Transportation Planning; Trip Generation; Trip Distribution; Traffic Assignment; Synthetic Demand Modelling	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	42	

Form DOT F 1700.7 (8-69)

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PREFACE

This final report presents an executive summary of the three interim reports prepared for the project "Use of Synthetic Demand Modelling Techniques in Transportation Planning for Small Urban Areas in Indiana". The titles of these three reports are:

I. "Framework for the Transferability of Trip Generation Parameters of Small Urban Areas"

II. "Evaluation and Development of Synthetic Trip Distribution Modelling Techniques as Applied to Small Urban Areas in Indiana"

III. "Effects of Simplifying Traffic-Zone and Street-Network Systems on the Accuracy of Traffic Assignments in Small Urban Areas in Indiana"

This summary will serve as a set of guidelines for the application of synthetic demand models in small urban areas. Recommendations have also been made as to the use of these guidelines.

The graduate research assistants who worked on this project were: Hani S. Mahmassani, James R. Mekemson, and Edward W. Hanscom. Another graduate research assistant, Karen L. Pickett, assisted in the preparation of the final report. The following planning division staff of the Indiana State Highway Commission provided much help and assistance: Mike Faris, John Mick and James Barr. The typing of the reports was most ably performed by Marian J. Sipes and Melody Gray. The constant guidance of Professor Harold L. Michael is gratefully acknowledged.

INTRODUCTION

Initiating a continuing, comprehensive, and coordinated transportation process is a considerable task that faces small metropolitan areas as their population reaches 50,000. Full-scale comprehensive transportation studies used in large areas have technical and financial requirements that often exceed the capabilities of these smaller areas. In most cases, such sophistication is not needed because the problems faced by smaller areas are different in nature and in complexity from those in larger areas. It is therefore imperative to develop and implement simplified alternative planning approaches which would greatly reduce the time and cost currently required by the "classical" transportation planning process. One approach to simplifying the transportation planning process is to eliminate the need for a full scale origin-destination (O-D) survey. This can be achieved by use of a synthetic travel demand modelling approach, whereby information traditionally obtained from the O-D survey is fabricated or synthesized through the use of parameters "borrowed" from "similar" areas.

The first phase of this study was aimed at reducing the cost and complexity of the conventional planning procedures by developing a framework for transferring trip frequency parameters, thus eliminating the need for conducting full-scale travel surveys. To this end, the objectives were:

1. Compilation and interpretation of various travel characteristics for the several small metropolitan areas in Indiana in which O-D studies have been conducted.
2. Comparison of these travel characteristics and identification of the other urban variables that explain these characteristics.
3. Detailed examination of trip generation parameters and models for those areas at three levels of aggregation: areawide, zonal and household; assessment of the stability and transferability of these parameters for synthetic modeling applications.

4. Development of a generalized framework for the transferability of trip frequency (generation) parameters and models.

The second phase of the study concentrated solely on the trip distribution part of the modelling process. The most commonly used trip distribution model is the gravity model in which calibration of the model primarily involves the establishment of the appropriate travel time impedance function. This phase of the research evaluated the performance of some of the various suggested synthetic gravity model calibration techniques and developed an improved procedure for synthetic self calibration of the gravity model. The same small urban areas of Indiana, as were examined in the trip generation phase, were used here. In addition, the complete transportation modelling data sets from three of these urban areas were used for detailed analysis and testing. The five major tasks were to:

1. Summarize the travel time statistics of the study areas and relate these statistics to other urban area characteristics. Determine if these statistics will be of any use in other urban areas in which the transportation planning process is to be implemented or updated.
2. Investigate the sensitivity of the gravity model with respect to friction factor errors introduced by the use of borrowed or standardized friction factors.
3. Investigate the possibility of using areawide travel time statistics and other variables in a self-calibrating gravity model.
4. Investigate the possibility of using origin zone specific travel time statistics in a synthetically self-calibrating gravity model.
5. Evaluate and make recommendations as to what method of synthetic trip distribution modelling should be used in the transportation planning process for small urban areas.

In the third and final phase of this endeavor, a study was made to determine if the complexity of urban travel forecasting could be reduced by simplifying traffic-zone and street-network systems without sacrificing accuracy in traffic assignments. This phase of the study considered simplification of several forms using transportation network and travel data from two small Indiana urban areas. Alternative traffic-zone and street network systems were developed and tested for each city, then test results were compared by overall measures of traffic distribution and assignment accuracy, and by statistical analyses of network links stratified by volume group.

In the following sections are briefly summarized the major findings of the study including a set of guidelines for the application of synthetic demand models for estimating travel demand in small urban areas in Indiana. The guidelines indicate the recommendations for new transportation studies or updating existing studies.

SYNTHETIC TRIP GENERATION

The need for simplification of the transportation planning process in small urban areas is apparent. Various efforts have been undertaken in this direction. Recent efforts have examined the use of cross classification disaggregate models for generation analysis. This technique has been strongly suggested for synthetic modelling applications, especially in small urban areas. It consists of developing household trip rates for each household socio-economic category. Since the household is taken to be the basic unit of analysis, these models are behavioral in nature and should therefore be transferable from one area to another.

The stability and transferability of household trip rates between small and medium areas is one of the matters examined. In contrast to previous work done in this area, this study developed a framework for transferring travel frequency parameters at three levels of aggregation: areawide, zonal, and household. This theoretical framework is supported by empirical evidence derived from the comparison of parameters obtained from various study areas for each of the relevant levels of aggregation.

General Characteristics Of The Study Areas

This study was aimed at compiling information from those small and medium sized metropolitan areas in Indiana in which a detailed travel survey has been conducted and a transportation study performed. Seven metropolitan areas with population in the range of 50,000 to 250,000 were thus included in this study. These are: Anderson, Evansville, Fort Wayne, Lafayette, Muncie, South Bend, and Terre Haute. These areas are Standard Metropolitan Statistical Areas (SMSA's) as defined by the U.S. Bureau of Census, and the general characteristics of these urban areas are shown in Table 1.

Distribution Of Trips By Purpose

Trips are usually stratified into three types in urban transportation planning studies. These are:

- internal trips which are those with both ends within the study area cordon line,
- internal-external trips, with one end inside the study area and the other outside the cordon, and
- external-external or through trips, with both ends outside the study area.

Table 1. Study Areas' General Characteristics

	ANDERSON	EVANSVILLE	FORT WAYNE	LAFAYETTE	MUNCIE	SOUTH BEND	TERRE HAUTE
Survey Year	1971	1970	1961	1970	1971	1967	1971
Population	90,338	175,514	203,861	101,125	100,056	219,018	102,729
Occupied Dwelling Units	29,808	60,500	64,780	29,758	31,015	69,091	41,418
Auto per Household*	1.30	1.26	1.36	1.27	1.30	1.30	1.18
Auto per Household**	1.30	1.30	1.16	1.54	1.52	1.25	1.00
Persons per Household	3.03	2.90	3.15	3.40	3.33	3.17	2.48

---

* From Census Data for the SMSA -1970

** From Transportation Study Reports For Study Area (within Cordon Area)

On the average, 82.2 percent of the vehicle trips were found to be internal, 15.2 percent external-internal, and 2.6 percent through trips. These percentages are the (unweighted) averages of the respective percentages for each of the seven urban areas. The home interview survey, the most costly and time consuming element of the O-D survey, is the basis for determining internal trips for the base year. Inasmuch as the aim of this research effort was to examine synthetic techniques which would minimize or eliminate the need for the home interview survey, it essentially focused on internal trips.

Number and Definition of Trip Purposes. For smaller urban areas, stratification of internal trips into three purposes is usually adequate. These are: Home-Based Work (HBW), Home-Based Other (HBO), and Non-Home Based (NHB). In Table 2 are given the total internal vehicle trips by purpose along with their percentages. It was observed that the distribution by purpose of internal vehicle trips was not the same for all urban areas in Indiana. However, for an initial assumption (to be adjusted later in the process) in a synthetic modelling effort the following unweighted vehicle trip averages can be made: HBW - 16.5%; HBO - 46.9%; NHB - 36.0%.

Variation Within Urban Areas. A household level of analysis was used to investigate some of the factors behind the variation of trip purpose distribution between urban areas. A Chi-square test was used to test the hypothesis that the distribution by purpose of trips made by households was independent of the socio-economic characteristics of households (as reflected in auto ownership status), and the results led to the rejection of the independence hypothesis with 99.5% confidence. Therefore, the distribution of vehicle trips by purpose turned out to be significantly different between auto ownership groups.

Inasmuch as the trip distribution by purpose is significantly different for each socio-economic group, it would appear reasonable to assume that the overall trip distribution by purpose in two different urban areas would be the same,

Table 2. Distribution of Total Vehicle Trips by Purpose

City	HBW	HBO	NHB*	TOTAL
ANDERSON	47,105 (16.2)	145,958 (50.3)	97,139 (33.5)	290,202 (100)
EVANSVILLE	74,586 (16.5)	188,285 (41.6)	189,923 (41.9)	452,794 (100)
FORT WAYNE	90,203 (23.3)	146,990 (38.0)	150,029 (38.7)	387,222 (100)
LAFAYETTE	44,337 (15.0)	154,067 (52.1)	97,306 (32.9)	295,710 (100)
MUNCIE	38,591 (13.4)	159,017 (55.2)	90,641 (31.4)	288,249 (100)
SOUTH BEND	79,672 (15.1)	208,452 (39.3)	241,896 (45.6)	530,020 (100)
TERRE HAUTE	36,745 (15.7)	121,836 (52.1)	75,130 (32.2)	233,711 (100)

*Including Truck trips

(Numbers in parentheses are percentages)

Unweighted Average Percentages: HBW: 16.5%

HBO: 46.9%

NHB: 36.6%

if the socio-economic mix in these areas were similar. This implies that "borrowing" areawide percentages without first comparing the socio-economic mix of the two areas could lead to erroneous results.

Areawide Trip Frequency

"Areawide", as it is used in this context, describes the geographic unit of analysis which is the totality of the urban area for which a transportation study is being conducted. Areawide frequency measures are to be deduced based on aggregate areawide characteristics of the urban area. The following rates are the most commonly used descriptive measures of trip frequency:

- average number of trips per household
- average number of trips per person
- average number of trips per automobile.

The vehicle trips per household ranged from 5.64 to 9.94 per day, while vehicle trips per person varied from 1.90 to 3.22. This variability is to be expected since areawide travel demand reflects various urban area characteristics which are most likely different between the study areas.

Areawide household trip frequency parameters depend on the socio-economic mix of the households in the urban area under study. Thus, in order to transfer aggregate areawide parameters from one area to another, care must be taken to thoroughly compare the socio-economic characteristics of the households of those two areas. For gross areawide estimations, transferring aggregate trip frequency parameters between urban areas with roughly similar socio-economic characteristics is feasible. More detailed analysis and forecasting at a finer level of aggregation would most definitely not rely on borrowed aggregate areawide travel frequency parameters, but should try to borrow parameters developed at a finer level of aggregation, such as the traffic zone or the individual household.

Trip Generation Analysis At The Zonal Level

Multiple regression techniques are generally used to relate average zonal trips to the zonal socio-economic and land use characteristics. All seven study areas developed zonal trip generation equations. The trip purposes for which these equations were developed varied between the study areas; however, these equations were combined according to the three purposes defined for this study (HBW, HBO, and NHB) in order to have a basis for comparison.

The transferability of the internal vehicle trip production equations were investigated at two levels of detail:

1. For each urban area, the mean zonal value of trips produced for each purpose were predicted using the equations calibrated in other areas. Areawide mean zonal values of the independent variables were used for these predictions, which were in turn, compared to the corresponding observed values (from the O-D survey). The percent difference of the mean (difference between mean of estimated zonal trips and mean of observed zonal trips as a percent of the observed mean) was then calculated as a measure of the overall predictive ability of each equation in each urban area.
2. A more detailed evaluation was made for selected urban areas (based on data availability) by predicting zonal trips for each purpose using zonal values of the independent variables. These predictions were compared on a zone-by-zone basis to the corresponding O-D observations. The percent standard error of the estimate, expressed as a percentage of the mean value, was used to measure the overall predictive ability of an equation.

The investigation of the transferability of the trip attraction regression equations was limited to comparisons of the mean zonal trips (observed vs. estimated) for three of the study areas (Lafayette, Fort Wayne, Muncie). Overall, trip attraction equations can be transferred for the purpose of developing rough estimates that would be redefined later on in the process.

The results obtained in this study showed that zonal aggregate model parameters tend to be dependent on the particular zonal scheme for which the model was developed. They are therefore not readily transferable to a different zonal scheme in another urban area unless this scheme is very similar in size and composition to the initial one.

The disadvantages of aggregate zonal regression equations are of even greater concern in the case of home-based productions (HBW and HBO). These equations use zonal aggregate data and assume that the zones are homogeneous in terms of the socio-economic characteristics of the households in the zone; in many instances, this might not really be the case. Aggregation to the zonal level tends to conceal a considerable amount of the variation between individual households within a zone, thus masking the causal nature of the explanatory variables. These models are therefore not behavioral in nature, and, as a consequence, they are not sensitive to changes occurring at the basic decision level of tripmaking.

Trip Generation Analysis At The Disaggregate Household Level

Within the framework of the established transportation planning process, two types of disaggregate household trip generation models can be used: regression models calibrated with household data, and cross-classification (category analysis) models. The latter stratify households according to their socio-economic characteristics and provide estimates of the trip rates for each of the household categories. These models have numerous advantages over zonal

aggregate models. In addition, category analysis offers the following advantages over the regression technique:

- ability to express non-linear relationships
- distribution-free characteristic whereby no limiting assumptions as to the statistical distribution of the variables have to be made as in the case of regression analysis
- ease of understanding and simplicity of application
- ease of monitoring and updating using small disaggregate samples or even subjective judgment.

These reasons make cross-classification models preferable to regression models, especially for simplified transportation planning for small urban areas.

Cross-Classification Procedure. The cross classification technique for household trip production analysis stratifies household trip rates according to the major household socio-economic characteristics affecting trip making behavior. Extensive empirical evidence was examined to indicate that the two major determinants of household trip generation are auto ownership and household size. Households can therefore be categorized according to these two characteristics, and average trip rates for each household category (or cell) are then developed. In order to do so, trip rates (by trip purpose) for the individual households are computed and accumulated within each cell. The average number of trips made by households as well as the standard deviation are then computed for each household socio-economic group. These rates can be plotted and a smooth curve can be fitted to the observations.

Cross-Classified Vehicle Trip Rates for Lafayette and Evansville. Since appropriate disaggregate household data was available only in two of the study areas, Lafayette and Evansville, household cross-classified trip rates were developed only for these two urban areas. Trip rates were determined for each purpose (HBW, HBO, and NHB). Also, trips were accumulated within each household

socio-economic category, and average trip rates, as well as standard deviations, were computed for each category. In Figures 1 and 2 are shown total internal vehicle trip rates for Lafayette and Evansville, respectively.

Cell-by-cell comparisons of trip rates by purpose between the two urban areas were made using a series of t-tests. Only a few cells for all three purposes exhibited significant differences between the urban areas. Thus, the comparisons made strengthened the belief that behavioral disaggregate household models are transferable from one urban area to another, especially in the case of small urban areas, regardless of the socio-economic differences between them. In spite of several such differences between the urban areas of Lafayette and Evansville, the household trip rates were not significantly different, which means that the trip making behavior is in essence similar in these cities even though their aggregate travel patterns are different.

Bayesian Updating Of Trip Generation Information

Even though trip rates have been shown to be stable between small urban areas, it might be desirable to modify them so that they reflect local conditions more accurately. This can be done by updating the borrowed parameters using information particular to the area under study. This information may be either objective or subjective.

Bayesian techniques can be used to update trip rates developed by category analysis in a certain area before applying them in a different area. In this study, the methodology, as well as example applications, were described for two cases:

1. New information obtained from small disaggregate sample coupled with the prior information based on the borrowed travel data from a similar urban area.
2. New information derived from subjective judgment coupled with the prior information based on the borrowed travel data from a similar urban area.

Conclusions On Trip Generation Phase

1. The distribution of trips by purpose is significantly different between the study areas, and within an urban area, this distribution varies between socio-economic groups.
2. For small urban areas, differences in socio-economic characteristics constitute the major differentiating characteristics affecting trip frequency; the socio-economic mix in the study areas was indicated by the auto ownership distribution between households.
3. Caution should be exercised when borrowing zonal trip generation equations for use in urban areas other than the one where they were developed.
4. Home-Based Work zonal production equations have more potential for transferability than Home-Based Other equations because of the nature of the work trip.
5. Non-Home Based zonal production equations have good potential for transferability and thus can be used successfully in synthetic applications.
6. Zonal trip attraction regression equations can be used to synthesize zonal attractions in areas different from the ones where they were developed. Non-Home Based and Home-Based Work equations predict more accurately than Home-Based Other equations even though the latter predict within reasonable limits. However, it is recommended that the synthesized attractions be balanced with total productions as obtained by more accurate synthetic techniques.
7. Disaggregate household trip generation rates have stronger theoretical justification for transferability because they are behavioral in nature.
8. The number of levels needed within each variable in the cross-classification trip generation technique has been determined to be:

- Auto ownership: 0 cars, 1 car, 2 cars, 3 or more cars.
- Household size: 1, 2, 3, 4, 5 or more persons.

9. Bayesian statistics can be effectively used to update cross-classified household trip generation rates. Objective or subjective information can be used to update trip rates spatially as well as temporally.

Recommended Procedure For Synthetic Trip Generation Analysis In Small Urban Areas

This procedure is limited to internal vehicle trips. Before detailed trip generation analysis is undertaken, rough estimates can be obtained using the trip rates given in Table 2 and in other tables in Chapters 3 and 4 of the report, "Framework for the Transferability of Trip Generation Parameters of Small Urban Areas in Indiana" (1).

The following steps could next be followed:

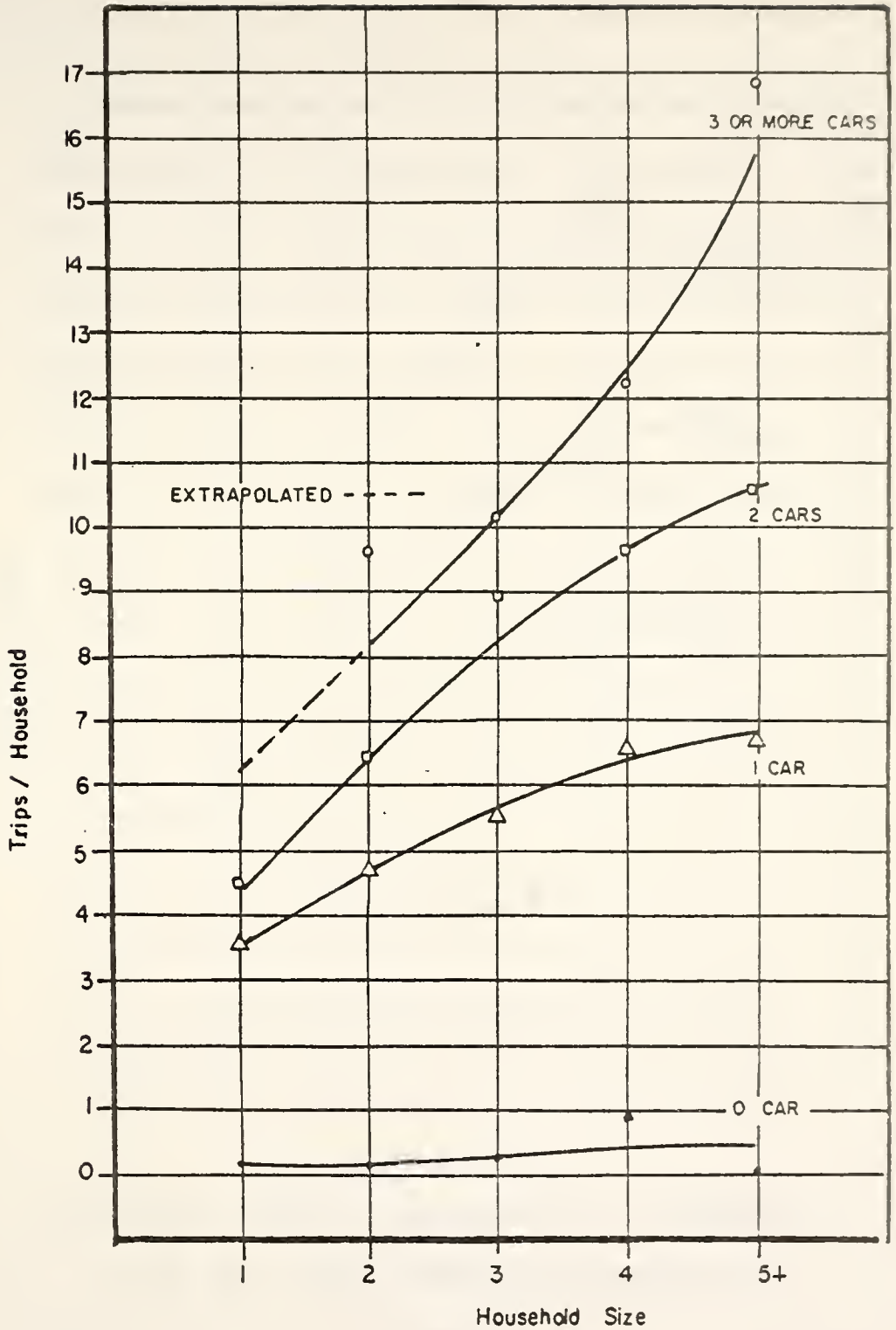
a. Establishing Control Totals

This could be done using the disaggregate trip rates as shown in Figures 1 and 2 whereby areawide control totals can be obtained by multiplying the appropriate rate by the areawide number of households in each category. More detailed information can be obtained in Reference 1.

Control totals are obtained for each purpose separately. It should be noted however that the Non-Home Based trip rates reported in Chapter 6 of Reference 1 do not include truck trips. The missing information can be supplied either by using the areawide vehicle trip rates reported in Chapter 4, or by using local survey information, or by multiplying the number obtained from the trip rates by a correction factor between 1.4 and 1.6 depending on the area being studied (this range is based on figures obtained from the study areas).

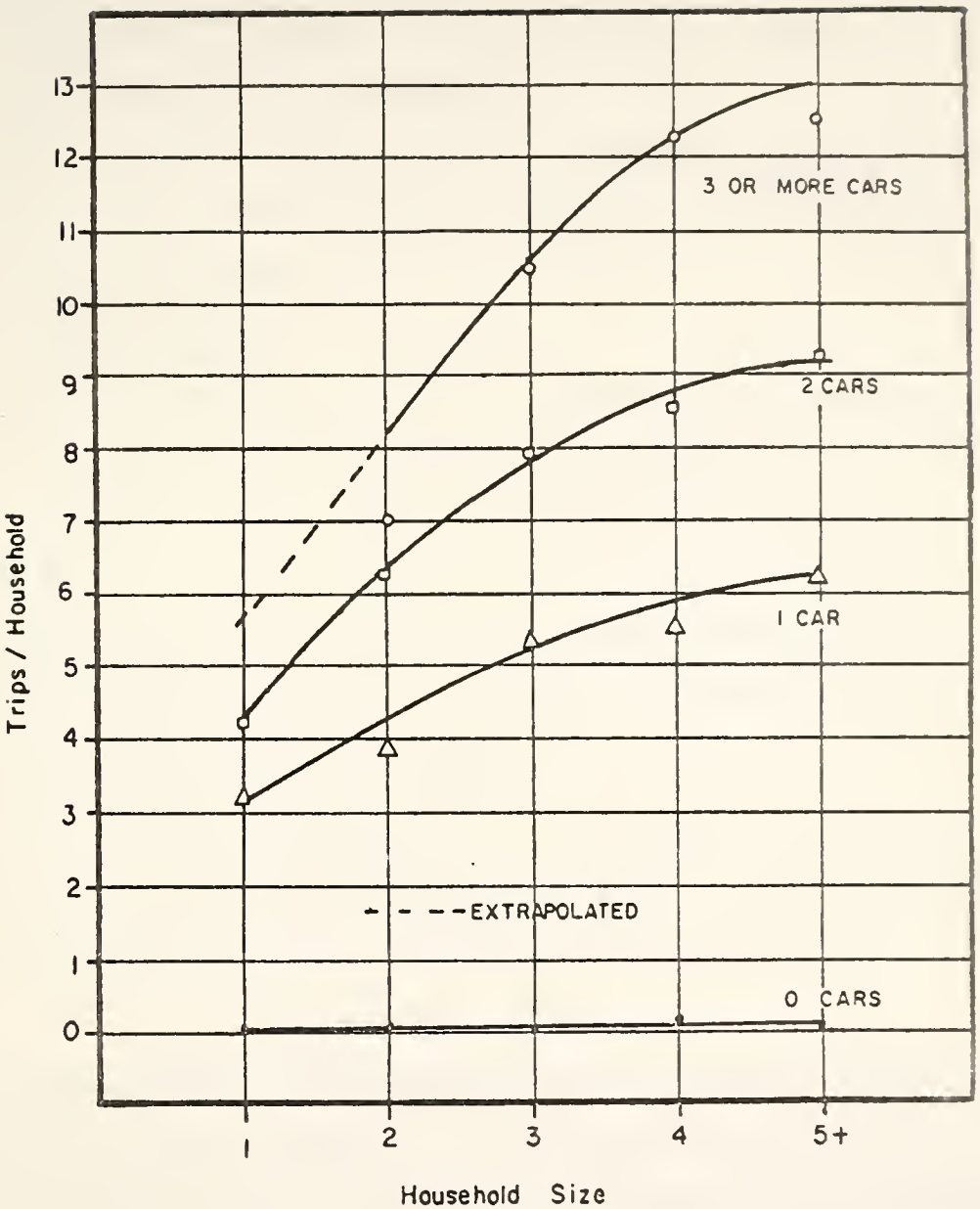
b. Trip Productions

Zonal values of the trip productions are needed. These can be obtained in the following way:



ALL VEHICLE TRIPS PER HOUSEHOLD BY HOUSEHOLD SIZE AND AUTO OWNERSHIP - LAFAYETTE

FIGURE 1



ALL VEHICLE TRIPS PER HOUSEHOLD BY HOUSEHOLD SIZE AND AUTO OWNERSHIP – EVANSVILLE

FIGURE 2

- HBW and HBO: using appropriate cross-classification tables and multiplying by the zonal number of households of each category. HBW productions can alternatively be determined using the equation recommended for that purpose in Chapter 5 of Reference 1.
- NHB: using synthetic equations as recommended in Chapter 5 of Reference 1.

The above zonal productions should be adjusted to agree with the control totals established earlier.

c. Trip Attractions

Regression equations can be used to synthesize zonal attractions provided that the total attractions are balanced by total productions for each purpose. In addition, special analyses might be needed for special generators unique to the study area.

Alternatively, attraction rates derived from national data can be used as described in Chapter 5, again with the condition that the total attractions are constrained to equal the total productions.

Finally, the whole process would have to be "tuned" so that the volumes assigned to the network (after the trip distribution and trip assignment steps are executed) compare favorably with the observed volume counts.

SYNTHETIC TRIP DISTRIBUTION

The second phase of the study concentrated on the trip distribution part of the demand modelling process (2). The performance of some of the various suggested synthetic gravity model calibration techniques were evaluated and an improved procedure for synthetic self-calibration of the gravity model was developed. Data from a wide range of small urban areas were used in determining variability of different travel characteristics. In addition, detailed travel data from three urban areas in Indiana, Lafayette, Anderson and Muncie, were used in the development of the recommended procedure.

Travel Time Characteristics

In Table 3 are given the relevant travel time characteristics for each of the study areas. A detailed analysis was conducted to evaluate the travel time characteristics and it was concluded that the prediction of average travel time based on the population size of the urban area alone would be of little practical use. This conclusion was derived from the fact that even though a positive correlation existed between average travel time and population size, the variance of the data about the regression line was substantial as measured by low R-squared values. This results in a regression equation with a confidence interval too large to be of practical use.

A comparison of home based work travel time frequency distributions for the Indiana study areas suggested that more careful selection of zonal terminal times might enable better comparisons to be made between the various study areas. Even though two distributions may look similar, however, the average travel times can differ significantly. Using travel time frequency distributions of one urban area to compare with the distributions generated from another urban area's synthetic trip distribution model is therefore of little benefit, unless it is previously known that the average travel time in the two areas are very close.

The above points verify the important fact that travel time statistics of an urban area are a unique result of the area's characteristics and are therefore difficult to compare with, or use for prediction in another study area.

Gravity Model Sensitivity Analysis

Standard Gravity Model Formulation. The gravity model has been the most widely used trip distribution technique, mainly because it is simple in concept and the procedure is well documented. Mathematically, the gravity model is stated as follows:

Table 3. Indiana Study Areas' Travel Time Statistics by Trip Purpose (in minutes)

City	Base Year Population	HBW		HBO		NHB	
		Average	Variance	Average	Variance	Average	Variance
Columbus	38000	9.34	13.88	8.33	11.60	8.84	11.30
Lafayette	79000	10.57	20.54	8.56	16.08	9.12	12.56
Anderson	89000	11.44	9.09	8.53	10.04	9.50	6.51
Terre Haute	90000	19.71	42.70	16.28	40.48	17.00	50.43
Muncie	100000	8.95	10.53	7.39*	9.27*	6.84	9.83
Evansville	176000	13.30	35.44	9.90*	25.98*	10.84	23.86
Fort Wayne	204000	8.69	10.60	7.25*	11.55*	7.37	8.71
South Bend	242000	15.27	41.79	10.99*	38.67*	12.92	41.22
Indianapolis	745000	20.19	80.99	11.06*	48.76*	13.00	69.16**

* Weighted combination of various home based trips.

**Trucks not included.

$$T_{ij} = \frac{P_i A_j F_{ij} K_{ij}}{\sum_{j=1}^{m} A_j F_{ij} K_{ij}}$$

where:

T_{ij} = trips produced in zone i and attracted to zone j,

P_i = trips produced by zone i,

A_j = trips attracted by zone j, and

F_{ij} = friction factor which expresses the effect of spatial separation on trip interchanges.

K_{ij} = zone-to-zone adjustment factors. (These factors are ignored in synthetic techniques because origin-destination data is needed to determine these values.)

Friction factors can be represented by a set of values at one minute time increments or by an equation of the form:

$$F(t) = Ct^{\alpha}e^{\beta t}$$

where:

F(t) = friction factor at time t,

C = constant of proportionality,

α = alpha, calibration parameter,

β = beta, calibration parameter, and

e = base of the natural logarithms.

Of particular interest to this study is the alternate form of this equation known as the negative exponential function where:

$$F(t) = Ce^{-\beta t}$$

with the variables defined as above.

Gravity Model Calibrations. The calibration of a gravity model basically involves repeated adjustments of a set of friction factors until the generated

gravity model travel time frequency distribution replicates the O-D survey travel time distribution within a predetermined error limit. This procedure, however, requires that an O-D survey has been performed in order to conduct the accuracy tests and the calibration itself.

In order to eliminate the cost and time involved in conducting an O-D survey, researchers and transportation planners have occasionally borrowed friction factors from other urban areas possessing similar characteristics, and then applied them to a new study area. An analysis was performed to evaluate the performance of the gravity model utilizing various synthetic techniques to assess possible errors that might be introduced by the borrowing of friction factors from a similar urban area or by the use of standardized friction factors or other synthetic techniques. The transportation study areas of Lafayette and Anderson were used for the purpose of this evaluation. The population sizes of these two areas are approximately equal, but spatial activity distributions and network impedances are quite different from each other.

This portion of the research consisted of four parts. First, tests were conducted to measure the sensitivity of the gravity model with respect to small errors in the friction factors. Simultaneously, these tests revealed the sensitivity of the gravity model with respect to the network characteristics and land use activity distributions of the individual study areas. Second, the variation of friction factors with respect to population size was investigated. This investigation involved the examination of the concept of similar urban areas from which friction factors may be borrowed. Third, an evaluation was performed using standardized α parameters in the gravity models for the Lafayette and Anderson urban areas. Fourth, the friction factors of Lafayette and Anderson were exchanged or borrowed from each other in order to test how borrowed friction factors may affect trip distribution modelling accuracies.

Sensitivity analysis of the gravity models for Lafayette and Anderson resulted in three important observations in regards to synthetic trip distribution modelling.

1. Acceptable model results will occur when the borrowed, or standardized friction factors are very similar to those that would have been normally calibrated from O-D survey data.
2. Acceptable model results may occur when synthetic methods are used because the urban area's gravity model is not sensitive to friction factor errors.
3. Acceptable model results may occur when one individual trip purpose error is offset by an opposite error in one or more of the other trip purposes.

Clearly, the first situation is the most preferred with the second also being acceptable. The third situation, however, is unacceptable because chance plays a larger role in the model's outcome than the procedure by which the friction factors were obtained. In addition, analysis of data from a number of small urban area transportation studies resulted in one other important conclusion: population size is an inadequate criterion by which to select a similar urban area for borrowing friction factors or their parameters.

Development and Testing Of Procedures For Synthetic Self-Calibration Of Gravity Models

Areawide Approach to Synthetic Self-Calibration of a Gravity Model. It is possible to relate mathematically the parameter of a friction factor equation to the spatial land use activity distribution and network impedances through the use of the areawide descriptors of mean travel time and travel time variance. This is because the friction factor equation of a gravity model represents the trip makers' destination choice process with respect to the spatial distribution of the land use activities as represented by the destination choice variable of

interzonal travel time. The aggregate effect of all the trip makers' destination choices result in a total travel pattern that can be approximately described in terms of the areawide travel time statistics of mean and variance.

Data used in the study of the areawide approach consisted of the β parameters of the negative exponential friction factor function, areawide average travel times and travel time variances, study area population, and study area density as computed or reported for eighteen small urban area transportation studies. Regression analysis was used to search for mathematical relationships between the β parameters and the areawide travel time statistics and any other variables of possible interest.

The self-calibrating β parameter procedure using the regressions equations was found to be not as reliable a procedure as the traditionally calibrated gravity model technique. Factors related to the poor performance of this procedure were considered in the development of the second approach to synthetic self-calibration of a gravity model.

Origin Zone Specific Approach to Synthetic Self-Calibration of a Gravity Model. The proposed synthetic procedure involves an origin zone specific self-calibrating model in which the only input data required are the zonal productions and attractions, a zone-to-zone travel time matrix (skim tree), and the origin zone terminal times. A travel time distribution is no longer needed for calibration, thereby eliminating the necessity for an O-D survey for internal-internal trips.

The study areas of Lafayette, Anderson, and Muncie, Indiana, were used to generate a data base because of data availability and the wide sampling space provided by the differing characteristics of these areas. The gravity models of these three areas were calibrated at the zonal level to generate the following information for each origin zone and for each trip purpose - HBW, HBO, and NHB trips:

β_i = negative exponential friction factor parameter for zone i of the origin zone calibrated gravity model,

O_i = trips originating from zone i,

$AVEO_i$ = opportunity average travel time for origin zone i when β_i equals 0.0, that is, friction factor of constant value 1.0,

$VARO_i$ = opportunity travel time variance for origin i when β_i equals 0.0,

AVE_i = origin specific average travel time for zone i of calibrated gravity model (same as O-D survey value),

VAR_i = origin specific travel time variance for zone i of calibrated gravity model, and

$TERM_i$ = origin zone terminal time.

The above variables were then used in a curve fitting regression procedure so as to find a relationship of the following form:

$$\beta_i = f(AVEO_i, AVE_i, VARO_i, VAR_i, TERM_i).$$

The initial regression analysis resulted in an equation form possessing very acceptable statistics for the curve fitting of the origin zone specific β parameters to their respective zonal travel time statistics of mean and variance. However, inspection of the residual plot revealed a greater than expected number of outliers. Careful review of the zonal data and a sensitivity analysis led to the following modifications:

- removal of the variable VAR_i from the analysis, and
- elimination of the simultaneous inclusion of both AVE_i and $AVEO_i$ in the regression equation.

A high correlation observed between $AVEO_i$ and AVE_i indicated that an indirect technique to estimating the β parameter could be possible. Consequently, a revised procedure was developed with $AVEO_i$ as the key variable.

Regression analysis of AVE_i on $AVEO_i$ and $TERM_i$ was accomplished by weighting the zonal data in order to properly balance the data by trip productions (origins) and by trip purpose. The regression analysis result for trip purpose HBW follows:

$$AVE_i = -0.4328 + 1.2761\ TERM_i + 0.8921\ (AVEO_i - TERM_i)$$

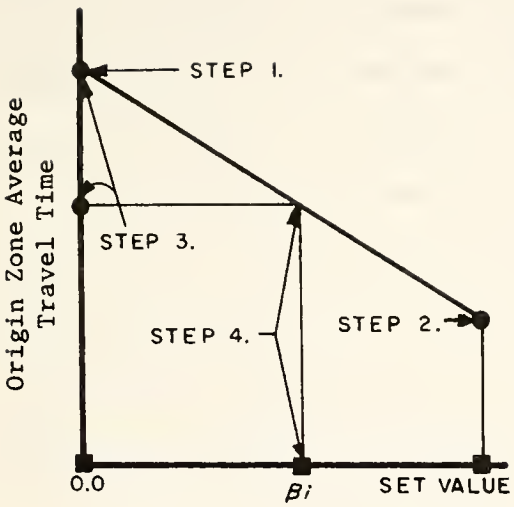
$$R^2 = .865$$

Similar equations for HBO and NHB trips were found, and all equations possessed R-squared values higher than those achieved in earlier attempts. The strong statistical fit of the equations shows the importance of $AVEO_i$, the opportunity average travel time, on the destination choice process.

Incorporation of the Estimating Equations into a Gravity Model. The recommended procedure for synthetic calibration was based on three assumptions regarding the interaction of origin zone average travel time and the zonal β parameter:

- The origin zone average travel time varies linearly with the origin zone β parameter.
- Zonal average travel time is independent of the β parameters of other zones.
- Zonal average travel time is independent of the attraction constraint iteration procedure.

The estimating equations of AVE_i, zonal average travel time, and the three assumptions listed above were incorporated into a gravity model procedure described below in conjunction with Figure 3.



Step 1 - Average at β equal zero (0.0) - $AVE0_i$

Step 2 - Average at β equal to a set value.

Step 3 - Average from regression equation, AVE_i

Step 4 - Interpolate for new β

Figure 3. Generalized Flow Chart of Synthetically Self-Calibrated, Origin Zone Specific Gravity Model as Applied to a Typical Zone

First, trips are distributed with all zonal β parameters equal to 0.0, and then the resulting zonal opportunity average travel times, $AVEO_i$, are computed. Second, trips are distributed with all origin zone β parameters equal to a preselected value, and then the origin zone average travel times are computed. Third, using the estimating equation for the appropriate trip purpose and the $AVEO_i$ values computed in step one, the origin zone average travel times, AVE_i, are determined. Fourth, using the data points from steps one and three and the estimated origin zone average travel times, AVE_i, the zonal β parameters are obtained through interpolation. All trips are then distributed using the interpolated origin zone specific β parameters.

Tests conducted on three separate study areas indicated that the proposed model is able to reproduce trip patterns as accurately as the traditionally calibrated gravity model procedure which is calibrated on O-D survey data. The opportunity average travel time, $AVEO_i$, is the key variable on which the model was developed and upon which the very acceptable model results are due.

Conclusions On Trip Distribution Phase

1. The need and importance of friction factors was established by the values of average travel time and traffic assignment statistics generated by trip distribution models without such time dependent factors.
2. The sensitivity of the gravity model to friction factor errors may be highly dependent upon the particular urban area being modelled.
3. A large variability exists in the correlation between population size and friction factors.
4. Because the variability of average travel time with respect to population size is large, the validation of a synthetic trip distribution model by comparing only the average travel times is not a valid approach.

5. While general shapes of travel time frequency distributions between two areas may appear quite similar, even a small variation or shift in a distribution can significantly alter average travel time and therefore also the accuracy of the model.
6. The most reliable synthetic trip distribution modelling technique is the origin zone specific synthetically self-calibrating gravity model.
7. The most important feature of the proposed procedure is its more direct linkage to the spatial distribution of land use activities within an urban area as quantified by the origin zone specific opportunity average travel times.
8. No collection of O-D survey data is needed for this procedure, nor is it necessary to find a similar urban area from which to borrow information or to which model validation comparisons are to be made.

Computer Program For The Recommended Procedure

A computer program JMGM was written for the purpose of using the recommended procedure with the UMODEL program of the UTPS package. A PLANPAC version of JMGM was also coded. A FORTRAN IV program is also available for incorporation into other packages. In Appendix is given a listing of this program.

EFFECTS OF SIMPLIFYING ZONE AND NETWORK SYSTEMS ON THE ACCURACY OF TRAFFIC ASSIGNMENT

The third phase of the study included an evaluation of the effects of simplifying zone and network systems on the accuracy of traffic assignment (3). The major factors of interest in this phase were average traffic zone size, use of census tracts as traffic zones, level of detail used in street networks, and method of traffic assignment used. Since a statistical design of experimentation was needed to test these factors and the possible interactions among them,

actual transportation network and travel data from two small urban areas in Indiana, Lafayette and Anderson, were used.

Alternative Traffic Zone Systems. For each urban area, alternative traffic zone systems were developed by substituting existing zones with smaller numbers of large zones. Only the internal zones were changed; all external zones were left intact. Larger zones were developed by combining existing zones into larger units. Only adjacent existing zones with similar land uses were combined into a larger zone. The numbers of vehicle trip productions and attractions (P's and A's) for a new zone were computed simply by adding together the P's and A's of its component zones. New zone systems were also developed from census tracts.

When a new zone was created, the centroid-connecting links to the old zones were changed. Only centroid connectors that were near the new zone centroid and collectively provide access to all nearby arterial and collector streets were chosen for the new zone.

Terminal Time and Intrazonal Travel Time Estimations. New terminal times and intrazonal travel times were established for each new zone. The terminal time for a new zone was set as the terminal time predominant among the existing zones from which the new zone was formed. The following equation was developed to compute the intrazonal travel times for new zones:

$$ITT_{new} = \frac{\Sigma(ITT_Z * P_Z)}{\sqrt{\Sigma P_Z}} \qquad Z = 1, 2, \ldots, n$$

where:

ITT_{new} = intrazonal travel time for new zone,

ITT_Z = intrazonal travel time for old zone,

n = no. of old zones within new zone, and

P_Z = areal function of old zone Z within new zone.

Alternative Network Systems. Two alternative street network systems were developed for each urban area, one being the full, existing coded network for an urban area. The second alternative was a reduced version of the full network, with all links on collector streets that carried less than 5000 vehicles per day removed. All links on arterial streets and high-volume collector streets were kept in the reduced networks, as well as in the full networks, since this level of street network detail was a minimum level at which all important links would still be represented.

Procedures For Data Collection And Analysis

For both Lafayette and Anderson, each alternative traffic-zone system was tested with each alternative street network. This resulted in ten zone-networks tests for Lafayette and eight for Anderson. Each test included a gravity model calibration, an all-or-nothing assignment, and a capacity restraint assignment. After all tests had been completed, the data resulting from the calibrations and assignments were analyzed.

In conducting the zone-network tests considerable street network and travel survey data were required. The street network data included a listing of all links with each link's length, travel time, ground count, and capacity. Travel survey data included vehicle-trip P's and A's for each zone, trip length distributions, and vehicle trips interchanged between external-internal and external-external zone pairs.

Each test followed the same set of procedures. These activities were:

- Preparation of network and travel data.
- Gravity Model calibration.
- Traffic assignment.

The final activity involved as its last step the comparison of assigned volumes with ground count volumes. This step produced the data on which most of the analyses were based.

Analyses of Data. The data from the test calibrations and assignments were analyzed by several methods. Aggregate methods were used to evaluate overall model calibrations and traffic assignments. Stratified methods were used to study traffic assignments in more detail.

Alpha values and intrazonal trip measurements were used in the aggregate analysis of model calibrations and trip distributions of all tests. Alpha values were examined for their stability with changes in the zone system or street network. Intrazonal trips, measured as a percentage of all internal trips, could be expected to increase as zone size increased. Total vehicle-miles travelled (VMT) and overall percent root mean-square error (% RMSE) were aggregate measures for comparing traffic assignments.

To study traffic assignments at a detailed level, the total population of links in a street network was stratified into volume groups based on ground count volumes.

Statistical analysis at the stratified level was conducted in two phases. In the first phase, the % RMSE's of volume groups in each assignment were analyzed for the main effects and certain interactions. The interests lay with the main effects of and possible interactions between certain factors: the number of traffic zones, the type of zone boundary, the type of street network, the method of traffic assignment, and the volume group. Two-way interactions were examined and multiple-factor analyses of variance (ANOVA's) were run and compared to determine main effects and interactions.

For the second phase of stratified analysis, observations were the absolute differences between the assigned volumes and ground counts on individual links. Links on a network are not independent of each other and neither are their traffic volumes. Without independent observations, parametric statistical methods lack validity. For this reason, these data were analyzed by nonparametric methods using Freidman rank sums.

Analyses Of Test Results

Definite patterns appeared as to how zone and network factors affect values of the alpha parameter in gravity model calibration. Reducing the number of zones seemed to reduce the alphas for HBW trips, while the alphas of the other trip purposes were only slightly affected. Reducing the number of links in the network seemed to increase alphas for all trip purposes. Alpha values were more variable for Lafayette than for Anderson. This occurrence may have been due to differences in the characteristics of the two cities, to differences in the accuracy of the data from the two cities, or to the use of very large zones in Lafayette.

The effects of zone and network factors on overall VMT appeared small. Total VMT in capacity-restraint assignments generally varied less than 5% with changes in zone size. Reducing network detail increased total VMT for both cities.

Decreasing the number of zones tended to increase the % RMSE. Assigning traffic by capacity-restraint always reduced the % RMSE. The use of Capacity-restraint reduced the effect of the number of zones on the % RMSE. Reduced networks generally showed lower % RMSE's, while no real trend could be established for the effect of zone boundary type on overall % RMSE.

In the stratified analysis of % RMSE, three ANOVA's were run at a .05 level of significance. Observations were the % RMSE's by volume group for every traffic assignment. The ANOVA showed that three factors, number of zones, assignment method, and volume group, had particularly significant main effects on the accuracy of traffic assignments. Interactions between factors were few and generally inconsistent. The nonparametric, link-by-link analyses describe the main effects more fully.

The results of these analyses implied that several factors have effects on the accuracy of traffic assignments:

- Using fewer (and larger) zones tends to reduce the accuracy of traffic assignments;
- Capacity-restraint assignment is substantially more accurate than all-or-nothing assignment;
- Limited reduction in the detail of a street network will not materially affect the accuracy of traffic assignments on high volume streets;
- The boundaries of census tracts will serve as a basis for boundaries of traffic zones without adverse effects on assignment accuracy.

Guidelines For Zone System And Network Development

The purpose of this research was to study the effects of reducing the number of traffic zones and simplifying street networks on traffic assignment accuracy. The following proposed guidelines for establishing zone systems and network configurations in emerging metropolitan areas are the final results of this endeavor.

Zone size is a significant factor in the accuracy of traffic assignments. The average zone size for a transportation study area should not exceed 3 sq. mi., and no zone should exceed 15 sq. mi. in area. Otherwise, gross instability in friction factor parameters may occur. Use of 90 internal zones is suggested for small urban areas such as Lafayette and Anderson in order to achieve acceptable overall accuracy levels.

Census tract boundaries can be used successfully as a basis for establishing a traffic zone system. The inconsistencies that may occur between census tract boundaries and land use boundaries have little effect on traffic assignment accuracy.

A reduced street network, comprised only of collectors with an ADT over 5000 and all higher-class streets and highways, should be adequate for planning purposes.

Finally, capacity-restraint traffic assignment is suggested for assigning trips to accurately simulate ground counts. Not only is capacity-restraint assignment more accurate than all-or-nothing assignment, but capacity-restraint assignment also reduces the adverse impact that the use of a small number of zones can have on assignment accuracy.

CONCLUSIONS

In this report was summarized the findings of the project on synthetic demand modeling techniques in transportation planning for urban areas in Indiana. Only internal vehicle trips were considered and guidelines were developed for trip generation, trip distribution and traffic assignment parts of travel demand forecasting.

Efforts are being made by the planning staff of the Indiana State Highway Commission to implement the study results in several urban areas in Indiana. At present implementation in three urban areas are being undertaken.

Some of the results of this project are being used in Bloomington, Indiana. In particular, the internal trip generation information for Bloomington is being developed on the basis of the study results. Plans are being made to use the trip distribution part in the Lake-Porter (NIRPC) area as soon as a network becomes available. Use of the guidelines in the South Bend (MACOG) area will include both the distribution and assignment phases.

It is felt that the procedures developed in the study will greatly reduce the cost and time involved in data collection and model development efforts associated with conventional travel demand modeling process based on origin-destination survey. The information can be used either in connection with a new transportation study for an emerging metropolitan area or for updating of existing transportation plans.

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APPENDIX

COMPUTER PROGRAM FOR SYNTHETIC CALIBRATION OF GRAVITY MODEL

```
C     PROGRAMMED BY JIM MEKEMSON, PURDUE UNIVERSITY, SEPT. 1972          JMGM   1
C     IMPLEMENTED AT THE INDIANA STATE HIGHWAY COMMISSION BY MIKE FARRISJMGM   2
C                                                                        JMGM   3
C                                                                        JMGM   4
C     THIS IS THE CODE FOR ENTRY POINT MOD13B                            JMGM   5
C                                                                        JMGM   6
C                                                                        JMGM   7
C     ZONAL VARIABLES.                                                   JMGM   8
C                                                                        JMGM   9
C         1 - ZONE NUMBER                                                JMGM  10
C         2 - ZONAL PRODUCTIONS (OR ORIGINS)                             JMGM  11
C         3 - ZONAL ATTRACTIONS (OR DESTINATIONS)                        JMGM  12
C         4 - TERMINAL TIME, ORIGIN ZONE                                 JMGM  13
C         5 - INTRAZONAL TRAVEL TIME                                     JMGM  14
C         6 - ZONAL BETA(IZ)                                             JMGM  15
C         7 - GRAVITY MODEL DENOMINATOR(IZ)                              JMGM  16
C         8 - NEW ITERATED VALUE OF A(J)                                 JMGM  17
C         9 - SUM COMPUTED A(J) = SUM(IZ) T(I,J)                         JMGM  18
C        10 - ZONAL AVE. AT BETA=0.0                                     JMGM  19
C        11 - ZONAL VAR. AT BETA=0.0                                     JMGM  20
C        12 - ZONAL AVE. AT BETA=PBETA(TP) OR FINAL VALUE                JMGM  21
C        13 - ZONAL VAR. AT BETA=PBETA(TP) OR FINAL VALUE                JMGM  22
C        14 - USED ONLY AS WORKING STORAGE,  TEMPORARY FRICITON FACTOR   JMGM  23
C                                                                        JMGM  24
C     INITIALIZE ZONAL MATRIX                                            JMGM  25
C                                                                        JMGM  26
      IF((ITNO.NE.1).OR.(IZ.NE.1))RETURN                                 JMGM  27
      DO 30 I=5,13                                                       JMGM  28
      DO 30 J=1,OMAX                                                     JMGM  29
   30 Z(I,J)=0.0                                                         JMGM  30
C                                                                        JMGM  31
C************************************************************************JMGM  32
C************************************************************************JMGM  33
C                                                                        JMGM  34
C                                                                        JMGM  35
C     THIS IS THE CODE FOR ENTRY POINT MOD13C                            JMGM  36
C                                                                        JMGM  37
C                                                                        JMGM  38
      REAL*4 PBETA(3),FCTR(99)                                           JMGM  39
      PBETA(1)=0.15                                                      JMGM  40
      PBETA(2)=0.30                                                      JMGM  41
      PBETA(3)=0.30                                                      JMGM  42
C                                                                        JMGM  43
C************************************************************************JMGM  44
C************************************************************************JMGM  45
C                                                                        JMGM  46
C                                                                        JMGM  47
C     THIS IS THE CODE FOR ENTRY POINT MOD13D                            JMGM  48
C     ORIGIN ZONE SPECIFIC SYNTHETICALLY SELF-CALIBRATING GRAVITY MODEL  JMGM  49
C     INTERNAL-INTERNAL TRIPS ONLY↓                                      JMGM  50
C                                                                        JMGM  51
C                                                                        JMGM  52
C     USER PARAMETER INPUT VIA UPARMS                                    JMGM  53
C                                                                        JMGM  54
C         UPARMS(1) = 1   HBW                                            JMGM  55
C                     2   HBO                                            JMGM  56
C                     3   NHB                                            JMGM  57
C                                                                        JMGM  58
C         UPARMS(2) = 1   COMBINED REGRESSION EQUATIONS                  JMGM  59
C                     2   LAFAYETTE REGRESSION EQUATIONS                 JMGM  60
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C                     3   ANDERSON REGRESSION EQUATIONS                    JMGM  61
C                     4   MUNCIE REGRESSION EQUATIONS                      JMGM  62
C                                                                          JMGM  63
C         NOTE:  OMAX=DMAX= NUMBER OF INTERNAL ZONES ASSUMED.              JMGM  64
C                                                                          JMGM  65
      REAL*4 AVE,VAR,ATT,TVAR,SUM,TRIP,RAVE,SX,SXX,TOT                     JMGM  66
C                                                                          JMGM  67
C     INITIALIZE OR CONTINUE                                               JMGM  68
C                                                                          JMGM  69
      IF((ITNO.EQ.1).AND.(IZ.EQ.1))GO TO 101                               JMGM  70
      GO TO 100                                                            JMGM  71
C                                                                          JMGM  72
C     COMPUTE TOTAL TRIPS                                                  JMGM  73
C                                                                          JMGM  74
  101 TOT=0.0                                                              JMGM  75
      DO 20 J=1,OMAX                                                       JMGM  76
   20 TOT=TOT+Z(2,J)                                                       JMGM  77
C                                                                          JMGM  78
C     INITIALIZE                                                           JMGM  79
C                                                                          JMGM  80
      SX=0.0                                                               JMGM  81
      SXX=0.0                                                              JMGM  82
      ATT=0.0                                                              JMGM  83
      TVAR=0.0                                                             JMGM  84
      CITER=0                                                              JMGM  85
      AITER=2                                                              JMGM  86
      DO 21 J=1,OMAX                                                       JMGM  87
      Z(8,J)=Z(3,J)                                                        JMGM  88
   21 Z(7,J)=TOT                                                           JMGM  89
C                                                                          JMGM  90
C     ITERATION FLAGS FOR DECISION TREE.                                   JMGM  91
C                                                                          JMGM  92
C     CITER=CALIBRATION FLAG                                               JMGM  93
C         0 - BETA=0.0                                                     JMGM  94
C         1 - BETA=PBETA(TP)                                               JMGM  95
C         2 - BETA=CALIBRATED VALUE FROM REGRESSION EQUATIONS              JMGM  96
C                   AND INTERPOLATION.                                     JMGM  97
C                                                                          JMGM  98
C     AITER=ATTRACTION FLAG                                                JMGM  99
C         0 - BEGIN ATTRACTION ITERATION                                   JMGM 100
C         1 - CONTINUE ATTRACTION ITERATION                                JMGM 101
C         2 - ATTRACTION ITERATION COMPLETE, I.E. CLOSURE                  JMGM 102
C                                                                          JMGM 103
  100 IF(IZ.EQ.1)WRITE(6,50)ITNO,CITER,AITER                               JMGM 104
   50 FORMAT(10X,7HITNO = ,I5,10X,8HCITER = ,I5,10X,8HAITER = ,I5)         JMGM 105
      IF((CITER.EQ.1).AND.(AITER.EQ.0).AND.(IZ.EQ.1))GO TO 200             JMGM 106
      IF((CITER.EQ.2).AND.(AITER.EQ.0).AND.(IZ.EQ.1))GO TO 300             JMGM 107
   99 IF(AITER.EQ.0)GO TO 400                                              JMGM 108
      IF(AITER.EQ.1)GO TO 500                                              JMGM 109
      GO TO 600                                                            JMGM 110
C                                                                          JMGM 111
C.....................................................................     JMGM 112
C.....................................................................     JMGM 113
C                                                                          JMGM 114
C     CITER=1,AITER=0,IZ=1   SET BETA(I)'S AND FRICTION FACTORS TO GIVEN   JMGM 115
C                                                                          JMGM 116
  200 TP=UPARMS(1)                                                         JMGM 117
      DO 201 J=1,99                                                        JMGM 118
  201 FCTR(J)=EXP(-PBETA(TP)*J)                                            JMGM 119
      GO TO 99                                                             JMGM 120
```

```
C                                                                       JMGM 121
C.....................................................................JMGM 122
C.....................................................................JMGM 123
C                                                                       JMGM 124
C     CITER=2,AITER=0,IZ=1    FIND BETA(I) S FROM REGRESSION EQUA.      JMGM 125
C                                                                       JMGM 126
  300 RTP=UPARMS(1)+(UPARMS(2)-1)*3                                     JMGM 127
      ATT=0.0                                                           JMGM 128
      TVAR=0.0                                                          JMGM 129
      SX=0.0                                                            JMGM 130
      SXX=0.0                                                           JMGM 131
      DO 18 J=1,OMAX                                                    JMGM 132
      IF(Z(2,J).EQ.0.0)GO TO 18                                         JMGM 133
C                                                                       JMGM 134
C     COMPUTE RAVE,  AVERAGE FROM REGRESSION EQUATION                   JMGM 135
C                                                                       JMGM 136
C          AVE  = ZONAL AVERAGE TRAVEL TIME.                            JMGM 137
C          AVE0 = ZONAL AVERAGE TRAVEL TIME AT BETA = 0.0               JMGM 138
C          VAR  = ZONAL TRAVEL TIME VARIANCE AT CALIBRATED BETA VALUE.  JMGM 139
C          VAR0 = ZONAL TRAVEL TIME VARIANCE AT BETA = 0.0              JMGM 140
C          TERM = AVERAGE ORIGIN ZONE TERMINAL TIME.                    JMGM 141
C                                                                       JMGM 142
C                                                                       JMGM 143
      GO TO(1,2,3,4,5,6,7,8,9,10,11,12),RTP                             JMGM 144
C                                                                       JMGM 145
C                                                                       JMGM 146
C     COMBINED REGRESSION EQUATIONS-LAFAYETTE, ANDERSON, AND MUNCIE IND.JMGM 147
C                                                                       JMGM 148
C     HBW   R**2 = 0.865                                                JMGM 149
    1 RAVE=-0.4327+1.2761*Z(4,J)+0.8921*(Z(10,J)-Z(4,J))                JMGM 150
      GO TO 19                                                          JMGM 151
C                                                                       JMGM 152
C     HBO   R**2 = 0.877                                                JMGM 153
    2 RAVE=-0.7499+1.3548*Z(4,J)+0.7557*(Z(10,J)-Z(4,J))                JMGM 154
      GO TO 19                                                          JMGM 155
C                                                                       JMGM 156
C     NHB   R**2 = 0.735                                                JMGM 157
    3 RAVE=0.5245+1.3416*Z(4,J)+0.6073*(Z(10,J)-Z(4,J))                 JMGM 158
      GO TO 19                                                          JMGM 159
C                                                                       JMGM 160
C                                                                       JMGM 161
C     LAFAYETTE, INDIANA.                                               JMGM 162
C                                                                       JMGM 163
C     HBW   R**2 = .893    AREAWIDE VAR=22.99;  VAR0=24.99              JMGM 164
C     AVE=10.60;  AVE0=12.32;  VAR=12.17;  VAR0=14.00;  TERM=1.08       JMGM 165
    4 RAVE=-1.0681+1.0934*Z(4,J)+0.9328*(Z(10,J)-Z(4,J))                JMGM 166
      GO TO 19                                                          JMGM 167
C                                                                       JMGM 168
C     HBO   R**2 = .893    AREAWIDE VAR=18.63;  VAR0=25.54              JMGM 169
C     AVE=8.55;  AVE0=11.78;  VAR=10.78;  VAR0=15.63;  TERM=1.11        JMGM 170
    5 RAVE=-1.6791+1.1459*Z(4,J)+0.8397*(Z(10,J)-Z(4,J))                JMGM 171
      GO TO 19                                                          JMGM 172
C                                                                       JMGM 173
C     NHB   R**2 = .799    AREAWIDE VAR=14.09;  VAR0=17.75              JMGM 174
C     AVE=9.12;  AVE0=11.42;  VAR=9.94;  VAR0=12.91;  TERM=1.99         JMGM 175
    6 RAVE=0.2131+1.2823*Z(4,J)+0.6744*(Z(10,J)-Z(4,J))                 JMGM 176
      GO TO 19                                                          JMGM 177
C                                                                       JMGM 178
C                                                                       JMGM 179
C     ANDERSON, INDIANA                                                 JMGM 180
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C                                                                       JMGM 181
C     HBW   R**2 = .876    AREAWIDE VAR=9.61;  VAR0=9.51                JMGM 182
C     AVE=11.43;  AVE0=12.10;  VAR=6.53;  V0=7.12;  TERM=2.38           JMGM 183
    7 RAVE=-0.4650+1.1306*Z(4,J)+0.9467*(Z(10,J)-Z(4,J))                JMGM 184
      GO TO 19                                                          JMGM 185
C                                                                       JMGM 186
C     HBO   R**2 = .664    AREAWIDE VAR=9.51;  VAR0=11.10               JMGM 187
C     AVE=10.04;  AVE0=12.30;  VAR=7.84;  VAR0=5.20;  TERM=2.37         JMGM 188
    8 RAVE=1.0611+1.0640*Z(4,J)+0.6504*(Z(10,J)-Z(4,J))                 JMGM 189
      GO TO 19                                                          JMGM 190
C                                                                       JMGM 191
C     NHB   R**2= .210    AREAWIDE VAR=7.82;  VAR0=9.20                JMGM 192
C     AVE=9.50;  AVE0=11.72;  VAR=6.35;  VAR0=7.12;  TERM=2.64          JMGM 193
    9 RAVE=274556+1.0868*Z(4,J)+0.4280*(Z(10,J)-Z(4,J))                 JMGM 194
      GO TO 19                                                          JMGM 195
C                                                                       JMGM 196
C                                                                       JMGM 197
C     MUNCIE, INDIANA                                                   JMGM 198
C                                                                       JMGM 199
C     HBW   R**2 = .772    AREAWIDE VAR=11.16;  VAR0=11.51              JMGM 200
C     AVE=9.07;  AVE0=9.82;  VAR=7.06;  VAR0=7.11;  TERM=1.33           JMGM 201
   10 RAVE=0.8618+0.7448*Z(4,J)+0.8491*(Z(10,J)-Z(4,J))                 JMGM 202
      GO TO 19                                                          JMGM 203
C                                                                       JMGM 204
C     HBO   R**2 = .749    AREAWIDE VAR=9.27;  VAR0=11.83               JMGM 205
C     AVE=7.48;  AVE0=9.58;  VAR=6.40;  VAR0=7.79;  TERM=1.34           JMGM 206
   11 RAVE=0.1603+1.0595*Z(4,J)+0.7162*(Z(10,J)-Z(4,J))                 JMGM 207
      GO TO 19                                                          JMGM 208
C                                                                       JMGM 209
C     NHB   R**2 = .506    AREAWIDE VAR=7.89;  VAR0=9.28                JMGM 210
C     AVE=6.93;  AVE0=8.95;  VAR=5.65;  VAR0=6.65;  TERM=1.49           JMGM 211
   12 RAVE=0.7980+1.4192*Z(4,J)+0.5384*(Z(10,J)-Z(4,J))                 JMGM 212
C                                                                       JMGM 213
   19 CONTINUE                                                          JMGM 214
C                                                                       JMGM 215
C     COMPUTE BETA, LINEAR INTERPOLATION.                               JMGM 216
C                                                                       JMGM 217
      Z(6,J)=(PBETA(TP)/(Z(12,J)-Z(10,J)))*(RAVE-Z(10,J))               JMGM 218
      IF(Z(12,J).GT.Z(10,J))Z(6,J)=0.0                                  JMGM 219
      IF(Z(6,J).GT.0.5)Z(6,J)=0.5                                       JMGM 220
   18 CONTINUE                                                          JMGM 221
      GO TO 99                                                          JMGM 222
C                                                                       JMGM 223
C.....................................................................JMGM 224
C.....................................................................JMGM 225
C                                                                       JMGM 226
C     AITER=0, IZ=1      INITIALIZE BEFORE ATTRACTION ITERATION BEGINS. JMGM 227
C                                                                       JMGM 228
  400 DO 401 J=1,OMAX                                                   JMGM 229
      Z(8,J)=Z(3,J)                                                     JMGM 230
  401 Z(9,J)=0.0                                                        JMGM 231
      AITER=1                                                           JMGM 232
C                                                                       JMGM 233
C     BEGIN ATTRACTION ITERATION.                                       JMGM 234
C                                                                       JMGM 235
C     SUMJ A(J)*F(I,J)                                                  JMGM 236
C                                                                       JMGM 237
  500 Z(7,IZ)=0.0                                                       JMGM 238
      DO 501 J=1,OMAX                                                   JMGM 239
      IF(IZ.EQ.J)INT(J,1)=Z(5,J)                                        JMGM 240
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      IF(INT(J,1).EQ.0.0)GO TO 501                                      JMGM 241
      Z(14,J)=1.0                                                       JMGM 242
C     ADD TERMINAL TIMES TO SKIM TREE TRAVEL TIME.                      JMGM 243
      TIME=INT(J,1)+Z(4,IZ)+Z(4,J)                                      JMGM 244
      IF(TIME.GT.99)TIME=99                                             JMGM 245
      IF(CITER.EQ.1)Z(14,J)=FCTR(TIME)                                  JMGM 246
      IF(CITER.EQ.2)Z(14,J)=EXP(-Z(6,IZ)*TIME)                          JMGM 247
C     SAF = SAF + A * F                                                 JMGM 248
      Z(7,IZ)=Z(7,IZ)+Z(8,J)*Z(14,J)                                    JMGM 249
  501 CONTINUE                                                          JMGM 250
C                                                                       JMGM 251
C     SUM COMPUTED ATTRACTIONS                                          JMGM 252
C                                                                       JMGM 253
      DO 502 J=1,OMAX                                                   JMGM 254
      IF(INT(J,1).EQ.0.0)GO TO 502                                      JMGM 255
C     SA = SA + P * A * F / SAF                                         JMGM 256
      Z(9,J)=Z(9,J)+Z(2,IZ)*Z(8,J)*Z(14,J)/Z(7,IZ)                      JMGM 257
  502 CONTINUE                                                          JMGM 258
C                                                                       JMGM 259
C     IF IZ.EQ.OMAX,  TEST FOR CLOSURE                                  JMGM 260
C     IF IZ.LT.OMAX,  CONTINUE ITERATION                                JMGM 261
C                                                                       JMGM 262
      IF(IZ.EQ.OMAX)GO TO 700                                           JMGM 263
      RETURN 1                                                          JMGM 264
C                                                                       JMGM 265
C     COMPUTE ERROR FOR CLOSURE TEST                                    JMGM 266
C                                                                       JMGM 267
  700 SUM=0.0                                                           JMGM 268
      DO 701 J=1,OMAX                                                   JMGM 269
  701 SUM=SUM+ABS(Z(9,J)-Z(3,J))                                        JMGM 270
      SUM=SUM/TOT                                                       JMGM 271
C                                                                       JMGM 272
C     ONE PERCENT CLOSURE TEST                                          JMGM 273
C                                                                       JMGM 274
      IF(SUM.LT.0.01)GO TO 702                                          JMGM 275
C                                                                       JMGM 276
C     CLOSURE TEST FAILED,  COMPUTE NEW ATTRACTIONS.                    JMGM 277
C                                                                       JMGM 278
      DO 703 J=1,OMAX                                                   JMGM 279
      IF(Z(8,J).EQ.0.0)GO TO 703                                        JMGM 280
      Z(8,J)=Z(3,J)*Z(8,J)/Z(9,J)                                       JMGM 281
  703 Z(9,J)=0.0                                                        JMGM 282
      RETURN 1                                                          JMGM 283
C                                                                       JMGM 284
C     CLOSURE TEST PASSED.  SET AITER=2 FOR AVE. AND VAR. ITERATION.    JMGM 285
C                                                                       JMGM 286
  702 AITER=2                                                           JMGM 287
C                                                                       JMGM 288
C     IF CITER=2, SET ITNO=ITER-1 FOR LAST AVE. VAR. ITERATION.         JMGM 289
C                                                                       JMGM 290
      IF(CITER.EQ.2)ITNO=ITER-1                                         JMGM 291
      RETURN 1                                                          JMGM 292
C                                                                       JMGM 293
C.....................................................................JMGM 294
C.....................................................................JMGM 295
C                                                                       JMGM 296
C     AVERAGE AND VARIANCE COMPUTATION .                                JMGM 297
C                                                                       JMGM 298
C     INITIALIZE ZONAL AVE. AND VAR.                                    JMGM 299
C                                                                       JMGM 300
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  600 AVE=0.0                                                                    JMGM 301
      VAR=0.0                                                                    JMGM 302
      DO 599 J=1,ZONES                                                           JMGM 303
  599 TROUT(J,1)=0                                                               JMGM 304
      IF(((CITER.EQ.0).OR.(CITER.EQ.2)).AND.(IZ.EQ.1))GO TO 598                  JMGM 305
      GO TO 597                                                                  JMGM 306
  598 ATT=0.0                                                                    JMGM 307
      TVAR=0.0                                                                   JMGM 308
      SX=0.0                                                                     JMGM 309
      SXX=0.0                                                                    JMGM 310
C                                                                                JMGM 311
C     BEGIN AVE. AND VAR. COMPUTATION                                            JMGM 312
C                                                                                JMGM 313
C     IF ORIGIN ZONE PRODUCTION=0, SKIP AVE. AND VAR.                            JMGM 314
C                                                                                JMGM 315
  597 IF(Z(2,IZ).LE.1.0)GO TO 605                                                JMGM 316
      DO 601 J=1,OMAX                                                            JMGM 317
C                                                                                JMGM 318
C     COMPUTE CELL INTERCHANGE, I.E. TRIPS.                                      JMGM 319
C                                                                                JMGM 320
      IF(IZ.EQ.J)INT(J,1)=Z(5,J)                                                 JMGM 321
      IF(INT(J,1).EQ.0.0)GO TO 601                                               JMGM 322
      Z(14,J)=1                                                                  JMGM 323
      TIME=INT(J,1)+Z(4,IZ)+Z(4,J)                                               JMGM 324
      IF(TIME.GT.99)TIME=99                                                      JMGM 325
      IF(CITER.EQ.1)Z(14,J)=FCTR(TIME)                                           JMGM 326
      IF(CITER.EQ.2)Z(14,J)=EXP(-Z(6,IZ)*TIME)                                   JMGM 327
C     TRIP = P * A * F / SAF                                                     JMGM 328
      TRIP=Z(2,IZ)*Z(8,J)*Z(14,J)/Z(7,IZ)                                        JMGM 329
C                                                                                JMGM 330
C     SAVE TRIP IN TROUT IF LAST ITERATION, I.E. CITER=2                         JMGM 331
C                                                                                JMGM 332
      IF((CITER.EQ.2).AND.(AITER.EQ.2))TROUT(J,1)=TRIP                           JMGM 333
C                                                                                JMGM 334
C     SUM ZONAL TRAVEL TIMES.                                                    JMGM 335
C                                                                                JMGM 336
      AVE=AVE+TRIP*TIME                                                          JMGM 337
  601 CONTINUE                                                                   JMGM 338
C                                                                                JMGM 339
C     ADD ZONAL CONTRIBUTION TO AREAWIDE AVERAGE TRAVEL TIME                     JMGM 340
C     IF((CITER.EQ.0).OR.(CITER.EQ.2))                                           JMGM 341
C                                                                                JMGM 342
      IF((CITER.EQ.0).OR.(CITER.EQ.2))ATT=ATT+AVE/TOT                            JMGM 343
C                                                                                JMGM 344
C     COMPUTE ZONAL AVERAGE TRAVEL TIME                                          JMGM 345
C                                                                                JMGM 346
      AVE=AVE/Z(2,IZ)                                                            JMGM 347
C                                                                                JMGM 348
C     SAVE AVERAGE TRAVEL TIME AT BETA=0.0 IF CITER=0                            JMGM 349
C                                                                                JMGM 350
      IF(CITER.EQ.0)Z(10,IZ)=AVE                                                 JMGM 351
C                                                                                JMGM 352
C     SAVE AVERAGE TRAVEL TIME AT BETA=PBETA(TP) OR FINAL VALUE.                 JMGM 353
C                                                                                JMGM 354
      IF(CITER.NE.0)Z(12,IZ)=AVE                                                 JMGM 355
C                                                                                JMGM 356
C     COMPUTE ZONAL VARIANCE AND SAVE DATA FOR AREAWIDE VARIANCE                 JMGM 357
C                                                                                JMGM 358
      DO 602 J=1,OMAX                                                            JMGM 359
C                                                                                JMGM 360
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C     COMPUTE CELL INTERCHANGE, I.E. TRIP                                    JMGM 361
C                                                                            JMGM 362
      IF(INT(J,1).EQ.0.0)GO TO 602                                           JMGM 363
      TRIP=Z(2,IZ)*Z(8,J)*Z(14,J)/Z(7,IZ)                                    JMGM 364
C                                                                            JMGM 365
C     ADD SUM OF SQUARES FOR ZONAL VARIANCE                                  JMGM 366
C                                                                            JMGM 367
      VAR=VAR+TRIP*(TIME-AVE)**2                                             JMGM 368
C                                                                            JMGM 369
C     ADD SUM OF TIME AND SUM OF TIME SQUARED FOR AREAWIDE VARIANCE          JMGM 370
C     IF((CITER.EQ.0).OR.(CITER.EQ.2))                                       JMGM 371
C                                                                            JMGM 372
      IF(INT(J,1).EQ.0)GO TO 602                                             JMGM 373
      TIME=INT(J,1)+Z(4,IZ)+Z(4,J)                                           JMGM 374
      IF(TIME.GT.99)TIME=99                                                  JMGM 375
      IF((CITER.EQ.0).OR.(CITER.EQ.2))SX=SX+TRIP*TIME                        JMGM 376
      IF((CITER.EQ.0).OR.(CITER.EQ.2))SXX=SXX+TRIP*TIME**2                   JMGM 377
  602 CONTINUE                                                               JMGM 378
C                                                                            JMGM 379
C     SAVE ZONAL VARIANCE AT BETA=0.0 IF CITER=0.                            JMGM 380
C                                                                            JMGM 381
      IF(CITER.EQ.0)Z(11,IZ)=VAR/(Z(2,IZ)-1.0)                               JMGM 382
C                                                                            JMGM 383
C     SAVE ZONAL VARIANCE AT BETA=PBETA(TP) OR FINAL VALUE.                  JMGM 384
C                                                                            JMGM 385
      IF(CITER.NE.0)Z(13,IZ)=VAR/(Z(2,IZ)-1.0)                               JMGM 386
C                                                                            JMGM 387
C     IF((CITER.EQ. 0 OR 2).AND.(IZ.EQ.OMAX)) COMPUTE AREAWIDE VARIANCE      JMGM 388
C                                                                            JMGM 389
  605 IF(((CITER.EQ.0).OR.(CITER.EQ.2)).AND.(IZ.EQ.OMAX))TVAR=               JMGM 390
     1(SXX-SX**2/TOT)/(TOT-1.0)                                              JMGM 391
C                                                                            JMGM 392
C     IF IZ=OMAX INCREMENT CITER BY 1 AND SET AITER=0.  STMT 603             JMGM 393
C                                                                            JMGM 394
      IF(IZ.EQ.OMAX)GO TO 603                                                JMGM 395
C                                                                            JMGM 396
C     IF IZ.LT.OMAX,  CONTINUE ITERATION.                                    JMGM 397
C                                                                            JMGM 398
      RETURN 1                                                               JMGM 399
C                                                                            JMGM 400
  603 CITER=CITER+1                                                          JMGM 401
      IF(CITER.EQ.1)WRITE(6,606)ATT,TVAR                                     JMGM 402
  606 FORMAT(/10X,10HBETA = 0.0/10X,22HAVERAGE TRAVEL TIME = ,F10.3/         JMGM 403
     110X,23HTRAVEL TIME VARIANCE = ,F9.3/)                                  JMGM 404
      IF(CITER.EQ.3)WRITE(6,604)ATT,TVAR                                     JMGM 405
  604 FORMAT(/10X,22HAVERAGE TRAVEL TIME = ,F10.3/10X,23HTRAVEL TIME VARJMGM 406
     1IANCE = ,F9.3/)                                                        JMGM 407
      AITER=0                                                                JMGM 408
      RETURN 1                                                               JMGM 409
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